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Study on The Vortex Shedding Mechanism of Coupling Combustion Stabilizer with V-gutter and Strong Swirl Flow

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Abstract

Both the strong swirl and the flow around blunt bodies can form low velocity recirculation zone to stabilize combustion of high-speed gas. Compared with the vortex shedding mechanism of the V-gutter blunt, the computational results show that the vortex shedding mechanism of the coupling combustion stabilizer is controlled by the vortex of the swirling flow. Also, the flow around bluff body with swirling flow through the central opening can reduce drag, increase the length of the recirculation zone and reflux mass, and increase the number of vortexes so as to enhance the heat and mass transfer. Thus, coupling combustion stabilizer can enhance the stability of flame

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Keywords: Swirl flow; V-gutter; Vortex shedding; Vortex structure

1. Introduction

Strong swirl and a blunt body are two commonly used structure to form low velocity recirculation zone to stabilize combusting of high-speed gas [1], but the two kinds of vortex structure are different. After introducing the strong swirling, the vortex structure become the superposition of vortex motions in two directions. And the bluff body vortex is a single spanwise vortex. A V-gutter is a commonly used flame stabilizer. Opening a hole in the

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center of the square cylinder to study the comprehensive effect of the strong swirl fluid vortex and the bluff body vortex is a kind of new exploration.The calculation model of this article is the same as the one in Du Yiqing' s experiment of the [2]. The experiments were conducted in an open wind tunnel.

2. Numerical simulation of flow around a V-gutter

2.1. Geometric structure

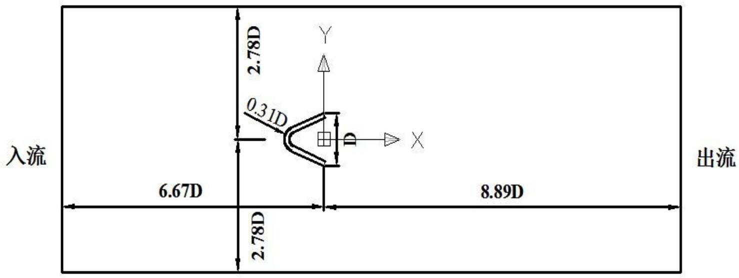


Fig. 1. Two-dimensional cross section for V-gutter

V-gutter's experimental parameters of Du Yiqing's is shown in the table below.

Table 1. The parameter value of V-gutter experiment.

Parameter	Value
Diameter	D=0.045m
Inlet velocity	U=30m/s
Reynolds number	Re=UD/v=615872
Blockage ratio	18%
Aspect ratio	2.22
Turbulence intensity	1%

2.2. Boundary conditions

The inlet conditions are decided by the velocity, Reynolds number. The walls are the solid walls. The outlet is decided by the pressure ; Two surfaces along the spanwise are symmetric boundary.

2.3. Numerical methods

As the V-gutter cross flow has its own characteristics, the experimental data of Barry Kiel [3] was used select the suited turbulence model. This paper selects several commonly used RANS turbulence models to do numerical verification, and the Realizable model's results are in good agreement with the experimental data. Therefore, this paper uses the model to simulate the flow around a V-gutter.

2.4. Vortex structure

Fig. 2 shows vortex street induced by the vortex shedding clearly. Vorticity concentrated near the corner of the blunt body. The vortex decreases gradually due to the viscous dissipation .

The vorticity nephogram clearly shows the shedding vortex from the upper and lower shear layer gradually dissipating with the downstream moving. The most centralized location for vorticity are the upper and lower edges of square cylinder.

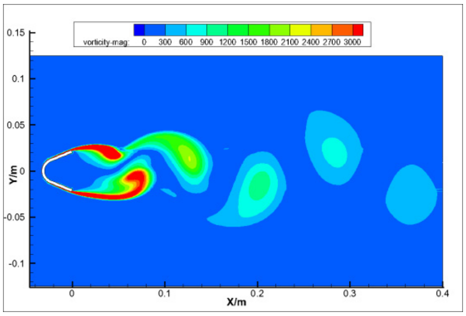


Fig. 2. Vorticity nephograms of cental cross section for V-gutter

3. Numerical simulation of V-gutter-swirl flow

3.1. Geometric structure

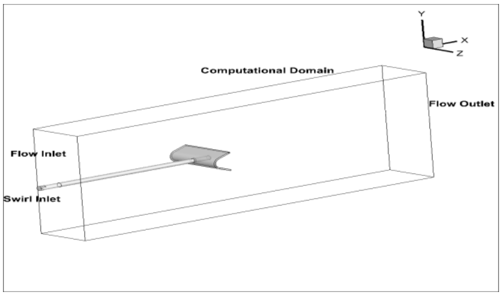


Fig. 3. Schematic diagram for V-gutter-swirl

The inlets of cyclone tube are on the upper and lower surfaces in the XY plane to produce swirl flow.

3.2. Boundary conditions

Swirling flow entrance is decided by velocity, and the other boundary conditions are the same as the numerical simulation of flow around a V-gutter's.

3.3. Data analysis

As the V-gutter cross flow has its own characteristics, the experimental data of Barry Kiel [3] was used select the

Table 2. The friction factors and the shedding cycle

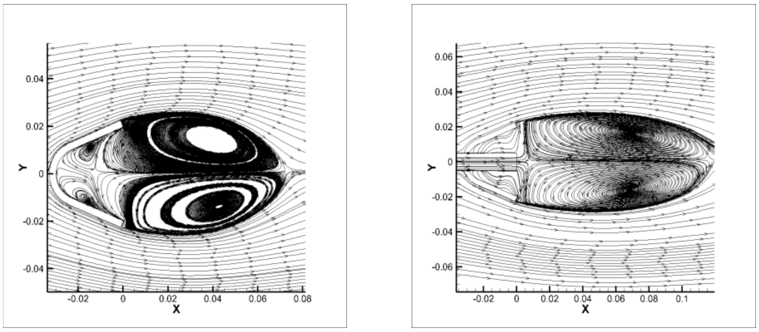
Mass flow rate kg/m3	C_D	C_D^{rms}	St
0	1.272	$6.58\times$ 10-3	0.247
1.25e-4	1.096	$2.95\times$ 10-4	0.193

C_D time averaged drag coefficient
C_D^{rms} ripple resistance coefficient
St St number

With the swirl mass flow, the time averaged drag coefficient C_D decreases for about 13.8%; ripple resistance coefficient C_D^{rms} and St number decreases decreases. This is useful for the vortex stability very much.

3.4. Characteristics of average circumfluence

Compared with the standard condition (a), the two large eddy become longer and more narrow, and the area of recirculation zone increases after introducing the swirling flow (b).



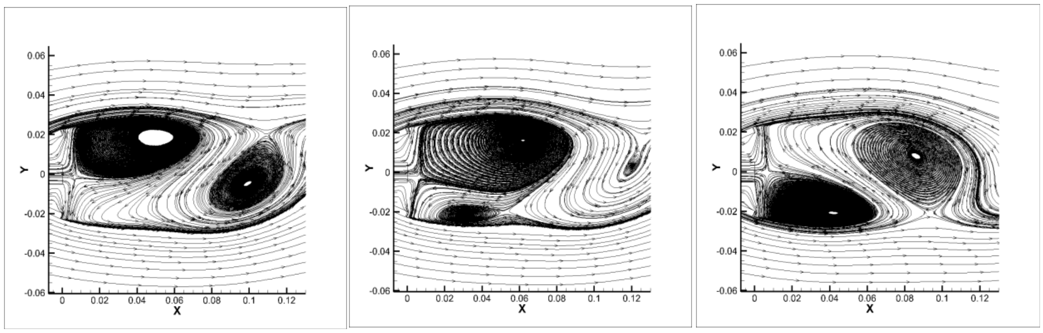
(a) Standard (b) S1

Fig. 4. Time average streamline chart of cental cross section for V-gutter-swirl

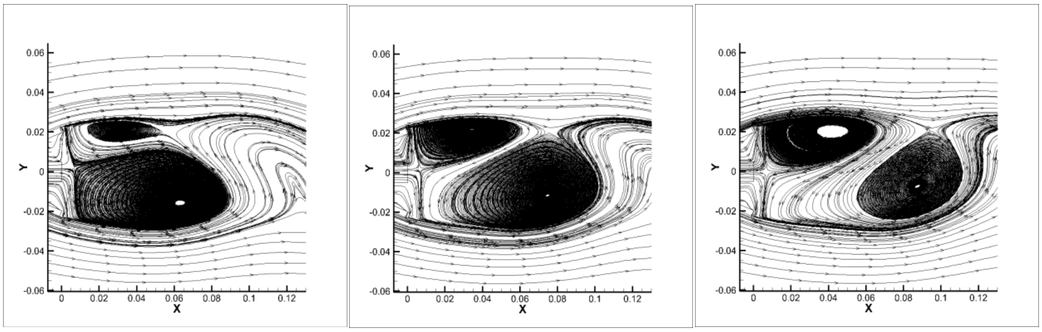
3.5. Pattern of the vortex shedding

Along with the increase of swirl mass flow and the enhance of the swirl strength, streamwise vortex becomes short and wide, flow field tends to be more uniform, swirling flow weakened the pulsing of the eddy, enhanced the transport characteristics of turbulent eddies, played an important role in reducing resistance and increasing the length of recirculation region and enlarging the mass rate of the back flow .

According to Fig. 5, T is the characteristic time of vortex shedding. From picture (a) to picture (f) , a complete vortex shedding process is displayed.



(a) t=T/6 (b) t=T/3 (c) t=T/2



(d) t=T2/3 (e) t=T5/6 (f) t=T

Fig. 5. Instantaneous streamline chart of cental cross section for V-gutter-swirl

4. Conclusions

This paper uses numerical simulation method to study the vortex shedding pattern of V-gutter and V-gutter-swirl flow. The conclusions obtained are as follows:

Under the comprehensive effect of the V-gutter vortex and the swirl flow vortex, the flow resistance will decrease, velocity's recovery ability will be enhanced, the fluctuation characteristics of the flow become weak, the average back-flow velocity and mass rate can increase. The area of recirculation zone increases .All these are benefit in the stability of combustion and the reduction of the drag. The non steady vortex shedding will be dominated by swirl flow vortex, and the vortex structure is more complex, and more vortex will be in favor of heat and mass transfer among the fluids.

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